



MEaSURES Greenland Ice Mapping Project (GIMP) Digital Elevation Model from GeoEye and WorldView Imagery, Version 1

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

Howat, I., A. Negrete, and B. Smith. 2017. *MEaSURES Greenland Ice Mapping Project (GIMP) Digital Elevation Model from GeoEye and WorldView Imagery, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. <https://doi.org/10.5067/H0KUYVF53Q8M>. [Date Accessed].

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National Snow and Ice Data Center

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1 DATA DESCRIPTION

This DEM was generated solely from in-track stereoscopic imagery, in which both images of the stereo pair were collected minutes apart along the same orbital pass. All elevations are registered to the following Operation IceBridge data sets: IceBridge ATM L1B Elevation and Return Strength, Version 2 ([ILATM1B](#)); and IceBridge LVIS L2 Geolocated Surface Elevation Product, Version 1 ([ILVIS2](#)). The DEM is posted at 30 m and divided into 36 tiles.

1.1 Parameters

This data set reports elevation in meters above the WGS84 Ellipsoid. In addition, ancillary files are available that contain pixel-level 1σ errors and data acquisition dates.

The following versions are available:

- A smoothed, single DEM ("fit") that provides a best continuous surface for visual display and applications based on slope information. 1σ errors and hillshade images are available as separate files.
- An unsmoothed, reference DEM ("reg") for evaluating pixel-level elevation changes. This DEM is available as both a quarterly time series and as a best data, single DEM. 1σ errors and day of acquisition are available as separate files. For the latter, each pixel has a date stamp that refers to the date of acquisition of the satellite image that was used to calculate the surface elevation for that pixel of that DEM. Date of acquisition is given in days since 1 January 2000.

Table 1 lists the non-data values for each file type:

Table 1. Non-data Values by File Type

DEM	File Type	Description	Key
fit	Elevation (dem)	DEM file	-9999 (no data)
	Error (err)	1σ error	-9999 (no data); inf (unregistered)
reg	Elevation (dem)	Merged best data DEM file	-9999 (no data)
	Error (err)	1σ error	-9999 (no data); inf (unregistered)
	Date (day)	Acquisition date	0 (no date)
	Elevation (dem)	Quarterly DEM file	-9999 (no data)
	Error (err)	1σ error	-9999 (no data); inf (unregistered)
	Date (day)	Acquisition date	0 (no date)

NOTE: Users of GIMP DEM or GIMP 2000 Image Mosaic images may find it helpful to mask out areas outside of the Greenland coastline using the corresponding 15 m, 30 m, or 90 m ocean mask image from the [MEaSURES Greenland Ice Mapping Project \(GIMP\) Land Ice and Ocean](#)

[Classification Mask, Version 1](#) data set. To apply the ocean mask, set the target mosaic image to the fill value (-9999) wherever the mask equals 1 (NSIDC has tested this approach).

1.2 File Information

1.2.1 Format

Data are provided as GeoTIFFs. Elevations and errors are stored as single precision, floating point numbers. Dates are stored as 16 bit integers. Hillshade data are stored as bytes.

1.2.2 Naming Convention

This section explains the file naming convention used for this data set:

Example File Names

- **_fit_**
 - tile_0_1_fit_30m_dem_v01.1.tif
 - tile_0_1_fit_30m_err_v01.1.tif
 - tile_0_1_fit_30m_hillshade_v01.1.tif
- **_reg_**
 - tile_0_1_reg_30m_dem_v01.1.tif
 - tile_0_1_reg_30m_err_v01.1.tif
 - tile_0_1_reg_30m_day_v01.1.tif
 - tile_0_1_reg_2012_3_30m_dem_v01.1.tif
 - tile_0_1_reg_2012_3_30m_err_v01.1.tif
 - tile_0_1_reg_2012_3_30m_day_v01.1.tif

Naming Convention

- Single DEMs
 - tile_[X_Y]_[fit or reg]_30m_[data]_[vXX.X].tif
- Quarterly Time Series
 - tile_[X_Y]_reg_[YYYY]_[Q]_30m_[data]_[vXX.X].tif

Refer to Table 2 for descriptions of the variables used in the file naming convention.

Table 2. File name variables and descriptions

Variable	Description
X_Y	Tile location. See Figure 1.
fit or reg	fit (best surface) or reg (best elevation)
YYYY	Year and quarter. Quarters span the following months:

Variable	Description
Q	Quarters of each collection year defined as: 1. (01 December of previous year through 31 March) 2. (01 March through 30 June) 3. (01 June through 30 September) 4. (01 September through 30 November)
data	<ul style="list-style-type: none"> dem: elevation hillshade: grayscale 3D representation of the DEM surface err: 1σ error day: date of acquisition, in days since 1 January, 2000¹
vXX.X	version number (currently v01.1)
¹ Noon on 1 January, 2000 is day 0.5	

1.3 Spatial Information

1.3.1 Coverage

Northernmost Latitude: 83° N
 Southernmost Latitude: 60° N
 Easternmost Longitude: 14° W
 Westernmost Longitude: 75° W

1.3.2 Resolution

This DEM is posted at 30 m.

1.3.3 Projection and Grid Description

The DEM is provided in a polar stereographic projection with a standard latitude of 70° N and rotation angle of -45° (sometimes specified as a longitude of 45° W). With this convention, the x-axis extends south from the North Pole along the 45° W meridian. Elevations refer to the WGS84 ellipsoid.

The data were gridded via bilinear interpolation to a grid with an origin at 59.1994° N, 55.7983° W and posted at 30 m. The grid was then partitioned into 36 tiles, 6 rows by 6 columns, each with dimensions of 15,000 rows by 8,310 columns (see Figure 1).

NOTE: The following tiles have been excluded from distribution because they do not contain any data: (0,0), (0,3), (4,0), (5,0), (5,1), and (5,5).

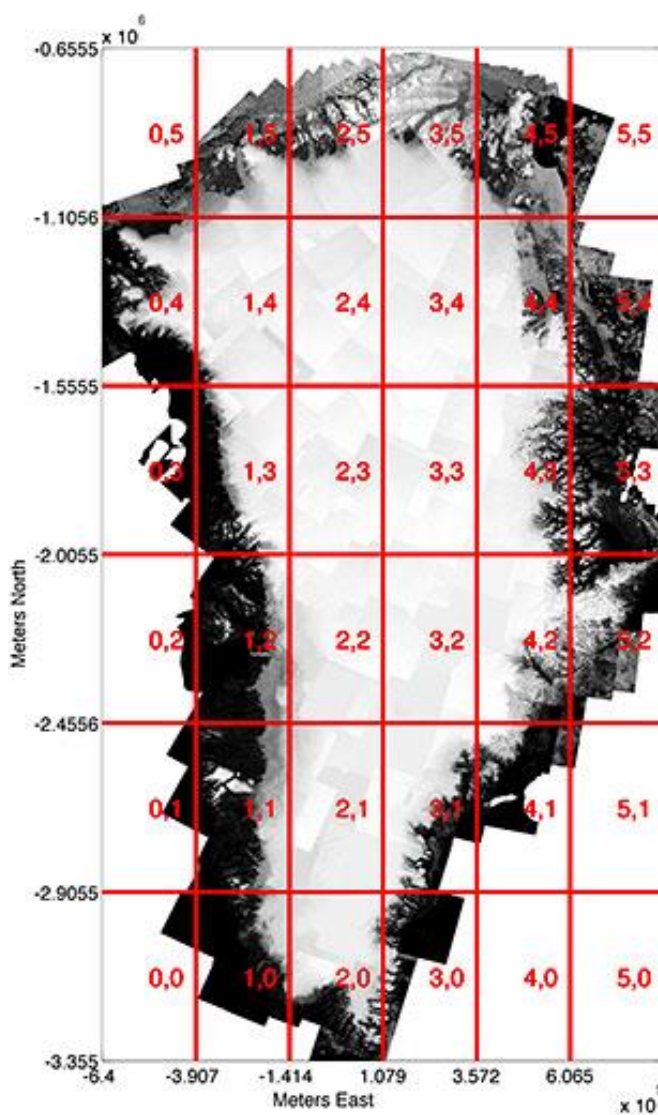


Figure 1. Tile locations and key for the DEM grid.

1.4 Temporal Information

1.4.1 Coverage

Images used for the DEMs were obtained between 2009–2015.

1.4.2 Resolution

The reg version of the DEM is available as a time-series of quarterly (3 month) mosaics.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

This DEM offers the cryospheric research community a new elevation data set over the Greenland Ice Sheet of sufficient quality for robust glaciological applications. It improves upon the [MEaSURES Greenland Ice Mapping Project \(GIMP\) Digital Elevation Model, Version 1](#) by utilizing sub-meter resolution, commercial imagery. Imagery for this project was provided by the [Polar Geospatial Center at the University of Minnesota](#). The underlying imagery acquired by DigitalGlobe, Inc.'s [constellation](#) of satellite imaging systems is available to researchers through the National Geospatial-Intelligence Agency's [NextView License](#) program.

2.2 Acquisition

The DEM was generated from the following data sources:

- GeoEye-1 panchromatic imagery (DigitalGlobe, Inc.)
- Worldview 1, 2, and 3 panchromatic imagery (DigitalGlobe, Inc.)
- MEaSURES Greenland Ice Mapping Project (GIMP) Digital Elevation Model, Version 1

2.3 Processing

2.3.1 Data Preparation

The DEMs in this data set were generated from in-track stereoscopic imagery in which both images of the stereo pair were collected minutes apart along the same orbital pass. Swath imagery was collected in strips, ranging from 12 km to 17 km wide and up to 300 km long, and segmented into scenes that overlap by approximately 20%. Individual, overlapping scenes were then paired for stereo processing. Using Surface Extraction from TIN-based Searchspace Minimization (SETSM) software (Noh and Howat, 2015), the investigators produced DEMs on High Performance Computing (HPC) systems at: the [Ohio Supercomputer Center](#); the San Diego Supercomputer Center ([Gordon](#)); and the National Center for Supercomputing Applications ([Blue Waters](#)). Raster DEMs with a resolution of 8 m were extracted and filtered based on the density of point matches, which removes erroneous surfaces due to clouds, water, sensor shadowing, and other sources. The filtered scenes were then mosaicked back into DEM strips using the iterative slope regression method of Nuth and Kaab (2011). This work was supported by multiple Ohio State University and National Science Foundation allocations.

2.3.2 Mosaicking

The following sections outline the mosaicking procedures for each version of the DEM.

2.3.2.1 reg

All DEM strips were first individually registered to Operation IceBridge Airborne Topographic Mapper (ATM) and Land, Vegetation and Ice Sensor (LVIS) LiDAR point cloud data. All years of data (beginning in 1993) were used for bare rock areas; ice-covered areas were limited to data collected within 30 days of image acquisition, as classified by the GIMP Land Classification Products.

Once registered, strips were indexed by the quarter of the year in which they were acquired (see Table 2). For each quarterly mosaic, all registered strips from that quarter were added sequentially in order of ascending quality score and registration error, with the best data remaining. Strips with 1σ registration errors > 4 m were excluded and treated as unregistered.

Registered strips were added in “underprint” mode — only empty pixels are filled, without data averaging, edge feathering or smoothing — so that each pixel provides the best estimate of elevation on that date. Once all registered strips were added, unregistered strips from the same quarter were added, in order of quality rank and lowest coregistration error, to fill gaps via coregistration with registered data. Following coregistration, the edges of unregistered strips were warped using a linear weighted adjustment inward 500 pixels. The error at pixels in the unregistered strip is calculated as the square root of the sum of the squares of the coregistration error and the mean error of registered strips used as reference for coregistration.

Once all strips overlapping existing, registered data were added via coregistration, any remaining gaps were filled with available unregistered data. The strip with the newest data coverage was added first as an anchor point. Strips which overlap this anchor were then coregistered and added using the same procedure described above. Errors for these unregistered clusters are assigned a value of “inf.”

The single, best data reference mosaic was created from the quarterly time series mosaics by selecting the pixels with the lowest registration error. Once the initial mosaic was generated, unregistered ice-free areas in the quarterly mosaics were added via coregistration.

2.3.2.2 fit

To create fit, the mosaic was initialized by adding to the mosaic grid the quality-controlled, level 1 strip with the most spatial coverage. Next, the overlapping strip with the best coregistration fit (lowest residual after fit) was added if it contributed 100 or more pixels of new data to the mosaic. A

linear, inverse-distance feathering was then applied to the overlapping region between the new and mosaicked data. Strips were added sequentially in this manner until no additional overlapping strips remained which met the 100 pixel requirement. If additional, non-overlapping strips were available, another cluster of coregistered data was initialized by again adding the highest quality-ranked strip with the greatest coverage and then adding overlapping data as before.

Once the mosaic was built, each cluster of coregistered data was registered to data from the Operation IceBridge Airborne Topographic Mapper (ATM) and the Land, Vegetation and Ice Sensor (LVIS) LiDAR point cloud. The 1σ error of the fit to the LiDAR point cloud is stored as a supplemental GeoTIFF file. Values of inf indicate that no registration data were available.

Following registration, GIMP ocean masks were applied and the DEM was merged with the [GIMP Digital Elevation Model, Version 1](#) to fill any remaining data gaps. These data were merged by interpolating the difference between the two DEMs across gap boundaries and adding the difference to the GIMP DEM Version 1 value. The pixel with the missing data was then filled with the adjusted value.

2.4 Quality, Errors, and Limitations

2.4.1 Quality Control

For quality control, all DEM strips were scored on a scale of 1 (best) through 5, and strips that scored a 4 or 5 were discarded. Strips with a score of 3 — typically mostly clear images with some cloud obscuration — were manually masked to remove erroneous surfaces. Quality controlled strips were then mosaicked using the iterative slope regression method for DEM coregistration and registration to LiDAR altimetry (Nuth and Kaab, 2011). This method is same as the original [GIMP DEM](#).

Two versions of the DEM are available. The "reg" DEM is an unsmoothed, reference DEM that provides best estimates of elevation and uncertainty for each pixel when the data were acquired. Date stamps and 1σ errors are provided as separate GeoTIFFs. reg is available as both a quarterly time series and as a single, merged best data mosaic. Because the edges of registered strips are not feathered or smoothed, surface discontinuities will be present in areas of rapid change.

The "fit" DEM offers users a smoothed, best continuous surface for visual display and for applications that require slope information such as supraglacial stream flow modeling. fit was produced by selecting adjoining strips that yielded the best alignment and then feathering strip edges through distance-weighted averaging. Once complete, the entire mosaic was then registered to all available Operation IceBridge Airborne Topographic Mapper data. This approach minimizes

surface discontinuities in areas of change at the expense of elevation confidence. fit is provided as a single mosaic derived from all available DEM data. 1σ errors are stored in separate GeoTIFFs.

2.4.2 Error Sources

The primary error sources are discussed in the preceding sections, namely discontinuities or a loss of certainty in the regions of change. In addition, discontinuities are apparent where gaps in fit were filled with lower-resolution GIMP DEM Version 1 data (refer to Figure 2). Note that these artifacts can be removed by masking out pixels with error values equal to inf in corresponding error GeoTIFFs.

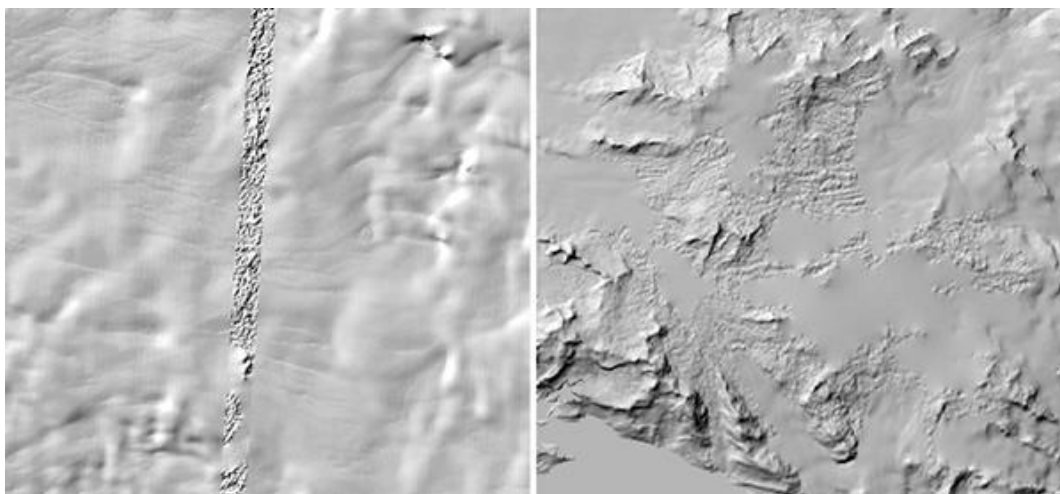


Figure 2. Examples of gap-filling in fit with noisier GIMP DEM Version 1 data.

3 SOFTWARE AND TOOLS

GeoTIFF files are most easily accessed using GIS software such as [QGIS](#) and [ArcGIS](#).

4 VERSION HISTORY

Table 3. Version History

Version	Description
V1 (March 2017)	Initial release
V1.1 (June 2020)	Version number appended to file names

5 RELATED DATA SETS

[MEaSURES Greenland Ice Mapping Project \(GIMP\) Digital Elevation Model, Version 1](#)
[Greenland Ice Sheet Mapping Project \(GIMP\)](#)
[IceBridge ATM L1B Elevation and Return Strength, Version 2](#)

IceBridge LVIS L2 Geolocated Surface Elevation Product, Version 1

6 RELATED WEBSITES

[MEaSURES Data at NSIDC](#)
[NASA MEaSURES Projects](#)
[DigitalGlobe](#)

7 CONTACTS AND ACKNOWLEDGMENTS

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Acknowledgements

These data were generated through a grant from the NASA Making Earth System Data Records for Use in Research Environments ([MEaSURES](#)) Program.

8 REFERENCES

Howat, I.M., A. Negrete, and B.E. Smith. 2014. The Greenland Ice Mapping Project (GIMP) land classification and surface elevation datasets. *The Cryosphere*: 1509-1518.

DOI: <http://dx.doi.org/10.5194/tc-8-1509-2014>.

Noh, M.J. and I.M. Howat. 2015. Automated stereo-photogrammetric DEM generation at high latitudes: Surface Extraction from TIN-Based Search Minimization (SETSM) validation and demonstration over glaciated regions. *GIScience and Remote Sensing* (52)2: 198-217.

DOI: <http://dx.doi.org/10.1080/15481603.2015.1008621>

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Noh, M. J. and I.M. Howat. 2017 (submitted). A fully automated system for generating digital elevation models from stereoscopic satellite imagery: Surface Extraction from TIN based Search-space Minimization (SETSM). *International Society for Photogrammetry and Remote Sensing (ISPRS) Journal of Photogrammetry and Remote Sensing*.

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doi: <http://dx.doi.org/10.5194/tc-5-271-2011>.

Levinsen, J.F., I.M. Howat, and C.C. Tscherning. 2013. Improving maps of ice sheet surface elevation change using combined laser altimeter and stereoscopic elevation model data. *Journal of Glaciology* 59(215): 524-532(9). doi: <http://dx.doi.org/10.3189/2013JoG12J114>.

9 DOCUMENT INFORMATION

9.1 Publication Date

14 May 2020

9.2 Date Last Updated

29 December 2020